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Research on Thermal Energy Recycling Utilization in High Temperature Mines

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Abstract

This paper designs an integrated system of mine cooling and thermal energy utilization with high temperature mines as the object of the research. The system can not only run in the refrigeration condition to provide low temperature cold source for cooling in high temperature mines, but also run in the heating condition in winter to provide heat source for ground buildings by recovering the thermal energy in the mine. This integrates the technology of heat pumps and mine cooling, involving in both mine cooling and heat recovery utilization in the mine. One system meets the dual demand for both high temperature mine cooling and ground building heating, which realizes the great reduction of equipment investment and operating cost as well as the recycling of energy.

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Keywords: high temperature mines; heat pump technology; mine cooling; building heating

1. Introduction

With the development of coal industry technical level and the increasing mining depth, high temperature mines become more and more and the thermal energy consumption of ground building heating and shaft cold prevention in modernized coal mines is getting higher.

In this paper, the project is targeting of the high temperature Mining Area 15, 16 in Yangchangwan Coal Mine One, An integrated system designs for mine cooling and thermal energy utilization. By using this system, mine

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cooling is realized, underground thermal disaster resources are recycled and utilized and the dual demand for both high temperature mine cooling and ground building heating are met. This system provides meaningful reference for the energy recycling and reduces equipment investment and operating cost.

2. Methodology

2.1. Overall plan of utilizing thermal energy in the mine

A system which combines mine cooling and waste heat utilization is designed on the ground and heat pump units with the function of either refrigeration operation or heating operation are adopted as the host devices.

- An integrated machine room is designed by taking both mine cooling and thermal heat utilization into consideration.
- In winter, a few of units work for mine cooling while most of them supply heat by recovering the return air afterheat and condensation heat in the mine.
- In summer, heat pump units work by two-stage refrigeration to provide cold water for mine cooling.
- The high and low pressure shell and tube heat exchanger is used in the mine to solve the problem of high hydrostatic pressure.
- A return air heat exchanger is installed in the main ventilating fan outlet. It is used to recover the return air afterheat in the mine in winter and to discharge condensation heat from mine cooling in summer.

2.2. Cooling load analysis

2.2.1. Ground atmospheric environment

The ground atmospheric environment has a great influence on the meteorological conditions of underground air flow because mine flows come from the external ground. Yangchangwan coal mine is located inside Lingwu city, Ningxia Hui Autonomous Region in China. This area has a semi-arid and semi-desert continental climate. Airflow temperature is led to rise in the mine in July and August although the inlet air from ground is low with temperature and humidity in summer (Ningxia Coal Design & Research Institute Co.Ltd.2014).

2.2.2. Geothermal geological environment

Take the Mining Area 15, 16 of Yangchangwan Coal Mine One as an example. Its constant temperature zone is 80 meters in depth, where the temperature is 15.92°C and the average geothermal gradient is 2.63°C/100m. It is a geothermal anomalous area because the primary and secondary thermal disaster area widely spreads here according to the data of eighteen observation wells of all mining areas. The primary high temperature zone (31°C or above) generally lies from -500 to -750m and the secondary high temperature zone (37°C or above) -750m below.

2.2.3. Operating environment in the mine

Operating environment in the mine includes heat dissipation from high temperature palisades and coal walls, heat dissipation from electromechanical equipment during operation, heat release from coal gangue during transportation, compression heat from air current, exothermic oxidation, and heat dissipation from staff and workers. The details are as follow:

- Heat dissipation from high temperature palisades and coal walls

The coal seam is deep buried and its ground temperature is high, so a lot of terrestrial heat is conveyed to the underground ventilation air current in the form of radiation and ventilating convection by means of high temperature palisades and coal walls. This is a key factor of causing high temperatures in the mine.

- Heat dissipation from electromechanical equipment during operation

Modernized large-scale mines are characterized by high mechanization and their electromechanical equipment has large installed capacities. A main reason of keeping the underground working face at high temperatures.

- Heat release from coal gangue during transportation

The temperature rise of the air current occurs when the coal gangue transfers their own heat to the air current during the process of being transported to the ground.

- Compression heat from air current

Mining Area 15, 16 is deep mined and part of them is over 800m in depth. Therefore, the air current is compressed naturally and its temperature rise becomes higher accordingly.

- Exothermic oxidation

Exothermic oxidation of coal and surrounding rocks containing coal and sulfur is also a thermal source of local temperature rise (Wang Wen et al. 2002).

- Heat dissipation from staff and workers

The quantity of heat that a man dissipates is concerned with his labor intensity and his physique, but its total amount is small so it has less influence on meteorological conditions.

2.2.4. Total Cooling load

In conclusion, there are many factors affecting underground thermal environment but among them the main reasons of thermal disaster in Yangchangwan coal mine are the high ground temperature and the large heat dissipation from electromechanical equipment, the summary sheet for the mine cooling load is shown in Table 1.

Table 1. Estimation for cooling load of mine cooling.

No.	Working face	Cooling load(kW)	Amount	Total cooling load(kW)
1	4800-meter long tunnel	5,060	1	5,060
2	1800-meter long tunnel	3,778	1	3,778
3	Tunneling face	640	7	4,480
Total				13,318

2.3. Heating load

2.3.1. Heating load for building heating

There mainly are office building, vertical shaft hoisting machine room, and material warehouse and so on in the surface plant of Mining Area 15, 16 of Yangchangwan Coal Mine One. The total building heating load is up to 1,457.5 kW.

2.3.2. Heating load for shaft cold prevention

In cold areas, shafts have to be heated to prevent them from freezing in winter so as to ensure safe production and personal safety. The outdoor design temperature for heating the air is -25.4°C which is the extreme minimum average temperature over the years and the air temperature of heated air mixing with other inlet air at the pithead is 2°C (China Coal Construction Association, 2006). The inlet air volume of Mining Area 15, 16 of Yangchangwan Coal Mine One is up to 150m³/s, so the heat consumption of shaft cold prevention is 6,560 kW.

2.3.3. Total heating load

Table 2. Heating load summary.

No.	Name	Building heating load(kW)
1	Shaft cold prevention	6,560
2	Building heating	1,457.5

3	Total	8,017.5
4	The coefficient of 1.2 times	9,621

2.4. Recyclable heat source

Waste heat in the high temperature mine is ultimately transferred to the ground by mine return air and cooling water from mine cooling. At the same time, the waste heat from them is recovered to become the main source of heating in winter.

2.4.1. Heat calculation and absorbing of mine return air

The total return air volume is $210\text{m}^3/\text{min}$, its relative humidity is 90% and the return air temperature is $18^\circ\text{C} \sim 24^\circ\text{C}$ in the Mining Area 15,16 of Yangchangwan Coal Mine One. In winter, the return air temperature is taken as 18°C and its relative humidity is 90% while it becomes 7°C and 95% respectively after heat is extracted, heat that can be extracted from the return air is 8,563kW.

In summer, the return air temperature is taken as 25°C and its relative humidity is 90% while it becomes 35°C and 90% respectively after heat is absorbed, the cooling capacity that can be provided is 11,631kW.

2.4.2. Condensation heat of mine cooling in winter

The thermal disaster mainly results from the heat dissipation of equipment in the working face in winter. Heat that can be extracted from underground cooling water is 4,731kW if the total installed capacity of underground working face is 18,415kW.

2.4.3. Low temperature heat source summary

Table 3. Statistical table of heat and cold resources.

Classification	Heating capacity(kW)	Cooling capacity(kW)
Mine return air	8,563	11,631
Condensation heat of mine cooling	4,731	0
Total	13,294	11,631

Therefore, recycling low temperature heat source in Mining Area 15, 16 of Yangchangwan Coal Mine One in winter can completely meet the heat demand of this mining area in winter, but also can discharge part of condensation heat from mining cooling by the mine return air system.

3. Result and discussion

3.1. Design of mine cooling and heat recycling system

3.1.1. Technological process

Fig.1 shows the underground cooling process in spring, summer and autumn. In summer, spring and autumn, the system works through two-stage refrigeration. The primary heat pump units refrigerate by large temperature difference and are responsible for the main cooling load. Its refrigerant water inlet temperature is designed to be 18°C and its outlet water temperature is 7°C . The secondary heat pump units are of low work efficiency and are responsible for the remaining cooling load. Its refrigerant water inlet temperature is 7°C and its outlet water temperature is 2.5°C . The primary chilled water of 2.5°C provided by the two-stage units is conveyed to the

underground cooling chamber and then exchanged to the low pressure secondary chilled water through the underground high and low heat exchanger. The secondary chilled water transfers the cold to each cooling spot where the cold is released by underground air cooler to realize mine cooling.

Fig.2 shows the process of underground cooling and waste heat recovery in winter. In winter, underground waste heat is ultimately transferred to the ground by the mine return air and the cooling water from underground cooling system. As the underground cooling load is less, only a few units work for underground cooling. Meanwhile, most of heat pump units of this system run in the heating condition and provide thermal energy for shaft cold prevention and building heating by recovering the low temperature heat of the mine return air and the underground cooling water.

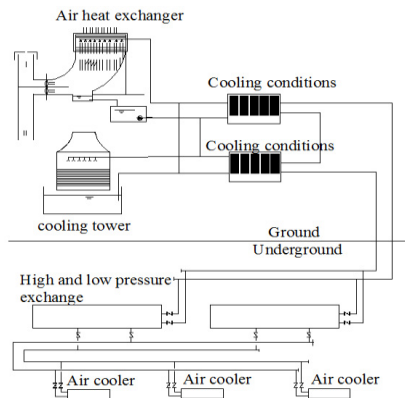


Fig. 1. Underground cooling process.

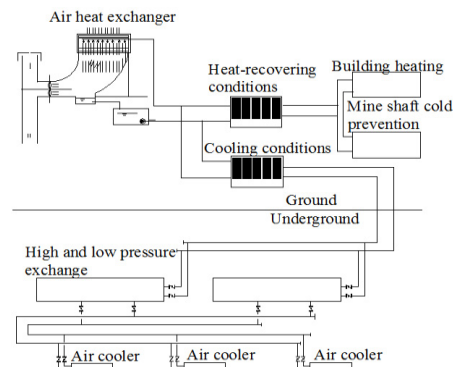


Fig. 2. underground cooling and waste heat recovery.

3.1.2. Determination of refrigeration parameters

According to Code for Design of Prevention and Elimination of Thermal Disaster in Coal Mines, the temperature of outlet water from refrigerator is requested not to be higher than 3°C when ground concentrated cooling mode is adopted (China Coal Construction Association, 2007). The low temperature of outlet water from refrigerator is convenient for the primary and the secondary system to adopt the way of indirect exchange. The big temperature difference between the outlet and the inlet can reduce the circulation volume of refrigerant water in the system, which contributes to the capacity reduction of devices transmitting refrigerant water. Finally the operating cost decreases. Therefore, the temperature of outlet water should be 2.5°C and that of return water should be 18°C in the ground concentrated refrigeration station.

3.1.3. Determination of the heat pump host

Four sets of flooded water source screw heat pump chiller with cooling capacity of 2,200kW is chosen as the units of the primary refrigeration for mine cooling and the waste heat recovery in winter; another four with cooling capacity of 1,600kW as the units of the secondary refrigeration for mine cooling.

Case 1: Cooling conditions in spring, summer and autumn

Four refrigeration stations are designed. Each refrigeration station has two sets of flooded water source screw heat pump chiller. One has a cooling capacity of 2,200kW and another one of 1,600kW. Two sets of heat pump chiller operate in series. Four sets of flooded water source screw heat pump chiller with cooling capacity of 2,200kW operate to provide the primary cold source for mine cooling. The temperature of water supply is 7.5°C. Another four sets with cooling capacity of 1,600kW operate to provide the secondary cold source. The temperature of water supply is 2.5°C. The total cooling capacity of them is up to 15,200 kW which is enough for the cooling load demand of 14,600kW.

Case 2: Working conditions of cooling and afterheat recovery in winter

There is only one refrigeration station running in winter to solve the problem of underground high temperature waste heat which is dissipated by mechanical equipment. Besides, the condensation heat can be used as the source of heating in winter. One system has two functions of both refrigerating and heating. Other three sets of flooded water source screw heat pump chiller, are used to recover the thermal energy of mine return air according to the outdoor temperature in winter and then provide heat for ground heating.

3.1.4. Plan for underground pressure coupling

The height of the coal mine from the ground down is taken as 800m and the static pressure is up to 7.84MPa after cold water standing. Pressure coupling must be adopted to lower the pressure in the mine where the cooling system works. The design involves two sets of high pressure heat exchanger. If taking safety margin into consideration, the heat exchange amount of each is 70% of cooling load and the heat exchange capacity of each is not less than 8MW.

3.1.5. Construction of the integrated machine room

The design introduces a comprehensive machine room integrating mine refrigeration and thermal energy recycling in the mine. The main frame structure of the integrated machine room is 42m in length, 20m in width and 7m in height. A cooling tower with the function of balancing heat is installed on the roof.

3.2. Economic analysis

3.2.1. Investment estimate

A heat pump system for mine cooling and thermal energy recovery, the underground high and low pressure heat exchanger system, the thermal energy exchange system of mine return air, the chilled water system, the cooling water system, the chemical water treatment system, the power supply and electrical system, the automatic control system and other related affiliated facilities. The total project cost is estimated to be RMB128,880,000.

Table 4. Total project investment.

Item project	Illustration	Total (RMB)
Mine cooling	Heat pump units, high and low pressure heat exchanger, air cooler, underground chamber, pumps, pipes, power distribution, etc.	947,60,000
Mine cooling and thermal energy utilization	Integrated machine room, water pump, water treatment equipment, pipeline and distribution, etc.	24,040,000
Thermal energy utilization	Return air heat exchanger, pithead heater, a complete set of civil engineering, water tank	10,080,000
Total		128,880,000

3.2.2. Investment comparison of underground concentrated cooling and ground coal slime boiler

- Investment estimate of underground concentrated cooling

Among traditional mine cooling modes, ground or underground concentrated cooling mode is more applicable for Mining Area 15, 16 of Yangchangwan Coal Mine. The comparative estimate of mine cooling is made by analyzing the underground concentrated cooling mode.

The maximum refrigerating capacity of a single machine is simply 3,300kW due to the limitation of transport in the mine. Therefore, the underground concentrated needs five sets of refrigeration units of 3,000kW at the same time need 200 meters cooling chamber. There is a need to design a cooling water system on the ground to cool the cooling water that is transferred to the ground cooling tower because the problem of condensation heat dissipation from refrigeration units cannot be solved in the mine.

The total project investment is estimated RMB122, 520,000.

- Investment estimate for heat source of ground coal slime boiler

If two sets of 10-ton coal slime boiler is used to supply heat for ground heating as planned by Yangchangwan coal mine, the cost is estimated to be RMB33, 380,000.

- Total project investment estimate: RMB155, 900,000.
- Investment reduced: RMB27, 020,000.
- Reduction of operation cost

Comparing with traditional underground cooling system, this system is designed on the ground and it is convenient for operation and maintenance. Therefore, the cost of operation and maintenance is saved.

Comparing with traditional heat source boiler, the heat pump system adopted is an effective way of saving energy and can greatly reduce the consumption of primary energy. Some researches show that heat pumps consume less energy than the section boiler room with 80% of heat efficiency in terms of energy utilization only if the heating co-efficiency performance of electric-driven heat pumps is more than 3. The temperature of the heat source recovered in this system is high and the heating COP of the heat pumps is far more than 3. In addition, the primary chilled water is transferred by using big temperature difference of 15.5°C in this design. It saves a lot of operating cost of water pumps.

4. Conclusion

The research designs an integrated system of mine cooling and heat recovery that comprehensively meets the dual requirement of high temperature mine cooling and ground building heating by making a comparative analysis of the cooling capacity demand of high temperature mine cooling, the heat demand of ground buildings and shaft cold prevention and the recyclable afterheat in high temperature mines.

This paper proposes that two-stage ground refrigeration is used for mine cooling, that primary chilled water is transferred by big temperature difference of 15.5°C and that high and low pressure heat exchanger is designed to solve the static pressure in high temperature mine.

Comparing with traditional underground concentrated refrigeration cooling and coal-fired boiler, this project initially saves RMB27, 020,000, reduces the operating cost and realizes the recycling and utilization of clean energy. Both energy conservation and emission reduction is realized and air is less polluted.

5. Acknowledgements

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